# Native plant community establishment on the Oldman River Dam

## Progress Report 1994

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# 1 INTRODUCTION

The Oldman River Dam was built in southwestern Alberta 10 km northeast of Pincher Creek, just east of the confluence of the Oldman, Castle, and Crowsnest Rivers. The primary purpose of the dam is to regulate flow to provide a dependable water supply throughout the year for domestic, municipal, industrial, agricultural, and recreational uses. Construction of the project began in 1986 and was completed in late 1991. Water was first stored in the spring of 1991. At Full Supply Level (FSL), the reservoir covers an estimated area of 2400 ha, and is approximately 24 km long and up to 3 km wide. Water depth exceeds 60 m in some parts.

The downstream face of the Oldman River Dam has a south aspect of approximately 90,000 $m^2$ that is divided into a series of five tiers by a vehicle track. The steep slopes (2.5:1) of the dam face and the adjoining west and east facing abutments (an additional 10,000 $m^2$) were reclaimed and revegetated. Native plants were chosen because they:

1. are well adapted to the harsh conditions under which they must establish and thrive (*i.e.* hot dry summers and cold dry winters),
2. are suitable for wildlife,
3. fit in well with the surrounding vegetation and landscape,
4. are self-sustaining and require little or no maintenance when established, and
5. are generally not as aggressive as exotic species.

Prior to 1986, methods of establishing a native plant community were not well documented in the reclamation literature especially on such steep slopes, in such a harsh environment (Kerr et al. 1993). The objective in revegetating the dam face was to establish an economical, self-sustaining native plant cover that would fit in aesthetically with the surrounding landscape. It was our objective to document the establishment of a native plant community and to record the successional stages of the vegetation establishment on the dam face.

The surface of the dam face consisted of closely packed, variable material (gravel, clay, pit run, etc.) (approximately 1 m deep). Surface layers of the abutments were of the naturally occurring materials from which all vegetation and topsoil had been removed during dam construction. Soil tests on surface material from both areas revealed no substances that would be inhibitory to plant establishment (Carrington, pers. comm.).

In early spring (1991) the surface of both areas was scarified with the toothed bucket of a backhoe. Topsoil (with vegetation) was removed with a loader from a native *Agropyron-Stipa-Koeleria* grassland on a nearby south aspect situated below FSL and spread immediately on the dam face at an approximate depth of 15-20 cm. Large rocks were removed. Topsoil was packed using a Bombardier.

On all areas, except for the uppermost slope and the abutments, a light application of 10-51-0 fertilizer was broadcast at a rate of approximately 2 kg/ha using an all-terrain vehicle (application rates are what were recommended however due to conditions on the slope these rates are only approximate). Using a Truax range drill, areas were seeded with a mixture of equal parts of 'Walsh' western wheatgrass, 'Revenue' slender wheatgrass, and 'Elbee' northern wheatgrass at a rate of approximately 5 kg/ha along with 2 kg/ha oats (as a nurse crop) (Hardy BBT, 1989). On small areas of the steepest slopes, seed was broadcast and raked in by hand. Except for a small area on the west side of the dam, oat straw was spread at an approximate rate of 5 tonnes/ha and crimped into the topsoil. The cover crop was cut twice in the 1991 season; once in July and again in September. All cut plant material was removed from the slopes.

On the uppermost slope of the dam and the adjacent abutments, fertilizer and seeds were applied with a broadcast seeder drawn behind an all-terrain vehicle. The slopes (except for one small area facing south) were packed using a D3 caterpillar. On these steeper slopes, straw was not crimped but topsoil was mulched with wood fibre and a plant resin tachyfier. In mid-late summer, some irrigation was used on the upper slope and abutments.

To determine the success of reclaiming the dam face, nine 0.5 x 1 m temporary quadrats were placed on various slopes and locations and monitored three times in the 1991 growing season; May 30, July 4, and August 22. Monitoring consisted of i) recording the abundance of the cover crop, ii) recording the abundance of the seeded wheatgrasses, and iii) recording regeneration of native vascular plants. No comparison was made to a native, undisturbed site. Results of this study were reported by Smreciu and Hobden (1992).

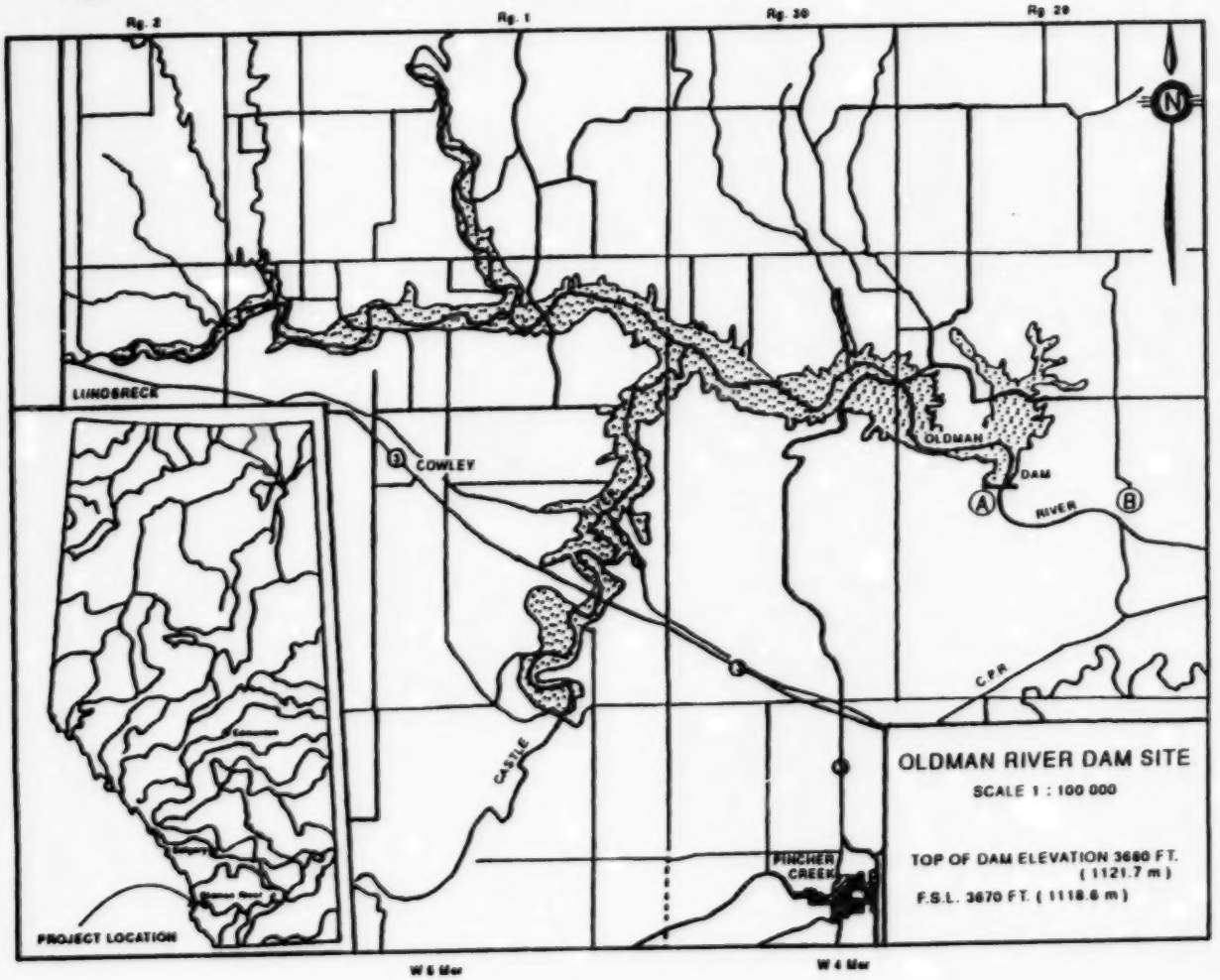
### 1.1 Objectives

In 1994, the establishment of native plants on the dam face was again surveyed. The objective was to determine if native plants were establishing on the dam and if the community that was establishing was comparable to a nearby, relatively undisturbed grassland with similar aspects.

## 2 METHODS

In late August, eighteen temporary plots were placed to include a representative sample from each of five areas on the dam: the lower, mid, and upper tiers, and the east and west abutments. Plots measured 1 x 0.5 m and were placed randomly within each of the areas of the dam. Five temporary plots were placed in a nearby (1.5-2 km east), relatively undisturbed native grassland (Sec 16, Twp 7, Rg 29, W4M) (Figure 1). These plots were also placed to accommodate the

Figure 1. Location of study plots at the Oldman River Dam.




A. Dam
B. Native grassland

variety of plants and grassland communities that existed on the south, east, and west aspects at that site. In 1991, there were two plots on the lowest tier, four on the mid slope area, one on the upper slope and one each on the east and west abutments. In 1994, two plots were monitored on the lower slope, seven on the mid slope, three on the upper slope, and three each on the east and west abutments. The number of quadrats was increased in 1994 from 1991 to encompass the apparent increase in diversity.

Individual plant species that occurred within each quadrat were recorded with an estimated abundance (recorded as % cover). Appendix 1 lists scientific and common names of all plant species (scientific names follow Moss 1983). The amount of litter and bare ground in each quadrat was also noted.

Anticipating that the quadrat sampling would not include all plant species that occurred in the establishing grassland on the dam or the undisturbed grassland area, species lists were prepared for both of these areas. These included all plant species observed in 1994 both within and outside of the sample quadrats.

## 3 RESULTS AND DISCUSSION

Natural re-establishment of a stable, self-sustaining native grassland community on a disturbed site (such as the dam) is an extremely long process of succession. The length of this process is determined by both edaphic and biotic factors including soil attributes, climate and weather, topography and aspect, moisture availability, and the availability of sources of plant propagula.

At the Oldman Dam site, it was assumed that the process could be hastened significantly by the introduction of large numbers of propagules; in this case by spreading native topsoil from a nearby, previously undisturbed, grassland. It was also assumed that using native topsoil (instead of soil from cultivated areas) would minimize invasion by weedy and exotic species. However, there was also a need to control the potential erosion on the site because the area is prone to high winds, and significant amounts of precipitation in short periods of time in the summer months. To control erosion, a quick vegetative cover was considered necessary.

Oats were seeded to provide a rapid, short-term (1-2 years), stabilizing cover. Three *Agropyron* species were seeded to provide longer term stabilization of the slopes. The *Agropyron* species were chosen because they were native to the area. They are not highly competitive and would therefore, not inhibit establishment of other species. There was some concern that the nurse crop of oats would deplete the soil of both moisture and nutrients. However, because

native plants are adapted for growth and completion of their life cycles on nutrient and moisture deficient substrates, it was expected that they could successfully compete for limited resources.

To ensure that the oats would not persist they were cut and removed in the first year. The cover provided by the oats in each plot ranged from 1% to 26% in 1991 and comprised 69% of total vegetative cover. In 1994 this species had all but disappeared; only a trace of the cover crop was found in one area (Table 1).

All areas of the dam showed an increase in wheatgrass cover (Table 1). In 1991 the absolute cover of wheatgrasses, on average, was 3-7% of most areas (although two of the plots had a recorded wheatgrass absolute cover of 10% and 20%). In 1994, the average absolute cover ranged from 12% to 34% (although there was great variation among individual quadrats). In 1994, seeded wheatgrasses comprised 60% of the total existing vegetation.

In 1991, only 13 species were observed within the monitored plots on the dam face whereas in 1994 this number increased to 29. In 1991, 11 native plants were recorded (including the seeded wheatgrasses). These included primarily early successional species such as *Artemisia frigida*, *Aster ericoides*, *Sphaeralcea coccinea*, and *Vicia americana*, and some of the native grasses such as *Koeleria macrantha*, *Bouteloua gracilis*, and a *Stipa* species. Only two weedy, introduced species were present, and low percent covers were recorded in each of only three plots (Smreciu and Hobden 1992). In 1994, 24 different native species were observed including those mentioned above from the 1991 observations, as well as *Oxytropis monticola*, *Ratibida columnifera*, *Petalostemon purpureum*, *Linum rigidum*, *Liatris punctata*, and *Gaura coccinea* and others. The number of weedy and introduced species increased to seven (including the forage/reclamation species alfalfa, sweet clover, and crested wheatgrass). Annual weeds are not of concern as they will likely decrease as native plant cover increases. The invasion of persistent, competitive species such as alfalfa, sweet clover and crested wheatgrass is a concern because these can proliferate and reduce diversity, especially in a developing grassland such as on the dam. Although these are not abundant at this time, annual inspections will determine if control measures are necessary.

Total vegetation cover increased on the top tier of the dam and on the east and west abutments from 1991 to 1994 (Table 1). This was due to an increase in both seeded *Agropyron* species and some of the native plants. Total cover remained relatively constant on the mid/lower slopes of the dam. On these slopes, the dense cover of oats in 1991 was replaced in 1994 by cover provided by the seeded *Agropyron* species. The average total cover in each of the four areas ranged from 29% on the west abutment (east aspect) to 47% on the uppermost tier.

Table 1 A comparison of abundance of seeded and naturally establishing plants growing on the Oldman River Dam in 1991 and 1994 and in an nearby natural grassland. Total litter accumulation and bare ground percent were also recorded in 1994.

| | Estimated Cover(%) | |
|---|---|---|
| | 1991 | 1994 |
| **East Abutment** (west aspect) | | |
| Seeded *Agropyron* species | 3 | 19 |
| Seeded oats | 8 | 0 |
| Other species (avg. # of species/plot) | 1 (2) | 17 (11) |
| **TOTAL VEGETATION** | 12 | 36 |
| Litter | n/a | 17 |
| Bare Ground | n/a | 47 |
| Number of quadrats | 1 | 3 |
| **West Abutment** (east aspect) | | |
| Seeded *Agropyron* species | 4 | 12 |
| Seeded oats | 1 | 0 |
| Other species (avg. # of species/plot) | t*(2) | 17 (5) |
| **TOTAL VEGETATION** | 5 | 29 |
| Litter | n/a | 17 |
| Bare Ground | n/a | 59 |
| Number of quadrats | 1 | 3 |
| **Upper Tier** (south aspect) | | |
| Seeded *Agropyron* species | 5 | 34 |
| Seeded oats | t | t |
| Other species (avg. # of species/plot) | 1 (4) | 13 (2) |
| **TOTAL VEGETATION** | 6 | 47 |
| Litter | n/a | 33 |
| Bare ground | n/a | 25 |
| Number of quadrats | 1 | 3 |

* t = trace
" natural ( not seeded)
n/a - data not available

**Table 1 (continued)** A comparison of abundance of seeded and naturally establishing plants growing on the Oldman River Dam in 1991 and 1994 and in an nearby natural grassland. Total litter accumulation and bare ground percent were also recorded in 1994.

| | Estimated Cover(%) | |
|---|---|---|
| | 1991 | 1994 |
| **Mid/Lower Tiers** (south aspect) | | |
| Seeded *Agropyron* species | 7 | 30 |
| Seeded oats | 26 | 0 |
| Other species (avg. # of species/plot) | 3 (6) | 9 (3) |
| TOTAL VEGETATION | 36 | 39 |
| Litter | n/a | 21 |
| Bare Ground | n/a | 42 |
| Number of quadrats | 6 | 9 |
| **Native (Undisturbed) Grassland** | | |
| *Agropyron* species | - | 13 ⁻ |
| Seeded oats | - | 0 |
| Other species (avg. # of species/plot) | - | 44 (8) |
| **TOTAL VEGETATION** | - | 57 |
| Litter | n/a | 29 |
| Bare Ground | n/a | 25 |
| Number of quadrats | - | 5 |

* t = trace
⁻ natural ( not seeded)
n/a - data not available

The diversity of non-seeded native species within plots (= average number of species/plot) increased from 1991 to 1994 on the west and east abutments but remained about the same (or decreased slightly) on the dam upper and mid/lower tiers (Table 1). Differences in diversity could be due to a number of factors; lower diversity could be related to greater cover density of the wheatgrasses and the resultant increase litter accumulation (i.e. upper and mid/lower tiers). In 1994, the lowest diversity of native plant species was observed on the uppermost tier of the dam, the same area that had the highest recorded wheatgrass cover. Low diversity was also recorded on the mid/lower slopes where wheatgrass cover was also high. The greatest diversity was observed on the east abutment where wheatgrass cover was low. The west abutment also had a low wheatgrass cover but did not have the corresponding high diversity. The lack of strict controls on this trial, allows us only to speculate that the high wheatgrass cover/low native species diversity observed on these areas could have been due to any of a combination of factors such as seeding method (broadcast vs. drilled), irrigation, mulch type (crimped straw vs. wood fibre), and slope type, aspect, steepness, and position.

Vegetation on the dam in 1994 was still dominated in most plots by the seeded wheatgrasses (with a cover as high as 50% in one plot and 30-50% in eight other plots), in contrast to the plots on the nearby established, undisturbed grassland where the cover provided by the wheatgrasses did not exceed 25% in any plot. The occurrence of *Agropyron smithii* and *A. trachycaulum* on all plots on the undisturbed grassland indicates that these species were appropriate choices for seeding on the dam face. The undisturbed grassland plots had a greater diversity (on average) than in plots on the dam, although the number of species/plot on the west aspect (east abutment) was greater than on the undisturbed grassland.

Total cover is extremely important in preventing soil erosion, particularly on susceptible sites such as the dam face and the adjoining abutments. However, total vegetation cover by itself should not be considered a criterion for successful reclamation. Early seral plant species (such as those expected on the revegetated site) often exhibit higher growth rates, lower root to total plant ratios, and higher nutrient uptake efficiency than later seral stage plants such as those expected in the undisturbed areas (Chambers et al., 1992). Although good cover values were recorded, these plants may not have sufficient root systems to completely control erosion, and are more easily disrupted by water flow, wind, and trampling and browsing by wildlife. The below-ground biomass is likely much greater on the relatively undisturbed site.

Total vegetation cover on the undisturbed grasslands area was 57% (Table 1) but ranged from 62-71% (one plot had only 20%). Average vegetation cover in each of the areas on the dam ranged from 29% to 47%, but variation was large among the plots. Four plots had a cover of

over 50% however, most were in the 25-45% range.

On the undisturbed grassland plots several species were present in all plots. These included both *Agropyron smithii* and *A. trachycaulum*, and *Liatris punctata*. The two grasses were present in most disturbed plots because these were seeded, but *L. punctata* was only present in one of the plots on the dam. *Liatris punctata* is a late seral species, and its eventual appearance in a large number of plots on the dam may be interpreted as an indicator of the development of a stable vegetation cover. *Artemisia frigida* was found in 80% of the undisturbed plots, about the same number as was found on the disturbed site and is therefore not a good indicator. Other possible indicator species are those that were found in over 50% of the undisturbed plots (*Calamovilfa longifolia*, *Carex filifolia*, and *Koeleria macrantha*) but occurred in only a few plots on the disturbed site. *Koeleria macrantha* was found in several plots in the disturbed areas but primarily on the east abutment (west aspect).

Plots on the native area had, on average, 25% bare ground (Table 1). A greater percentage of bare ground was recorded on the dam and abutments: 47% on east abutment; 59% on the west abutment; 33% on the uppermost tier; and 42% for the mid/lower slopes. There was great variation and some plots on the dam and abutments were comparable to plots in the native area. Although some erosion (primarily wind erosion) was observed on the dam and abutments, it was not extensive and was localized in a small areas. This indicates that the level of bare ground was acceptable at this time.

Forty one species were reported growing on the small, native grassland area (inside and outside of the plots) (Table 2). Only two of these were not native. Of the 41 species recorded, 17 were exclusive to the undisturbed grasslands and included two graminoid species (*Agropyron albicans* and *Calamovilfa longifolia*), three shrub species (*Amelanchier alnifolia*, *Juniperus horizontalis*, and *Rhus trilobata*) and 12 forbs including six legumes (Table 2). Several of the 17 species observed only on the undisturbed site are late successional species (e.g. *Aster laevis*, *Astragalus drummondii*, *A. crassicarpus*, and *Psoralea esculenta*) and would not yet be expected (at least not in large numbers) on the newly regenerating site. Some of these plants however, should be found on the disturbed site at later stages and, as with *Liatris punctata*, may be indicators of a move toward a stable community.

Plants that were observed on the disturbed site are those that propagate readily from vegetative propagules and organs, primarily roots and rhizomes (e.g. *Achillea millefolium*, *Artemisia frigida*, *A. ludoviciana*, *Antennaria parvifolia*, *Aster ericoides*, *Opuntia polyacantha*, *Hymenoxys richardsonii*, and *Linum lewisii*), pioneer species from seeds (*Chenopodium*

**Table 2** Plant species observed on the establishing grasslands on the Oldman River Dam and in a nearby native grassland. The asterisk indicates plant species occurring in plots.

| Taxa | Native | Occurrence | |
|---|---|---|---|
| | | Dam Grassland | Native Grassland |
| *Achillea millefolium* | X | X | |
| *Agropyron dasystachyum* | X | X* | |
| *Allium cernuum* | X | X | |
| *Artemisia ludoviciana* | X | X | |
| *Astragalus bisulcatus* | X | X | |
| *Astragalus gilviflorus* | X | X | |
| *Astragalus missouriensis* | X | X* | |
| *Chenopodium leptophyllum* | X | X | |
| *Cirsium undulatum* | X | X* | |
| *Erigeron caespitosus* | X | X | |
| *Gaillardia aristata* | X | X | |
| *Grindelia squarrosa* | X | X | |
| *Gutierrezia sarothrae* | X | X* | |
| *Helianthus annuus* | X | X | |
| *Heterotheca villosa* | X | X | |
| *Hymenoxys richardsonii* | X | X* | |
| *Linum rigidum* | X | X | |
| *Opuntia polyacantha* | X | X | |
| *Orobanche fasciculata* | X | X | |
| *Oxytropis monticola* | X | X* | |
| *Petalostemon purpureum* | X | X* | |
| *Potentilla pensylvanica* | X | X | |
| *Ratibida columnifera* | X | X* | |
| *Senecio canus* | X | X | |
| *Sphaeralcea coccinea* | X | X | |
| *Agropyron pectiniforme* | | X* | |
| *Artemisia absinthium* | | X | |
| *Avena sativa* | | X | |
| *Avena fatua* | | X | |
| *Bromus inermus* | | X | |
| *Cirsium vulgare* | | X | |
| *Cirsium arvense* | | X | |
| *Dactylis glomerata* | | X | |
| *Lactuca serriola* | | X | |
| *Lepidium campestre* | | X* | |
| *Medicago sativa* | | X* | |

**Table 2** Plant species observed on the establishing grasslands on the Oldman River Dam and in a nearby native grassland. The asterisk indicates plant species occurring in plots.

| Taxa | Native | Occurrence | |
|---|---|---|---|
| | | Dam Grassland | Native Grassland |
| *Melilotus officinalis* | | X* | |
| *Phleum pratense* | | X | |
| *Taraxacum officinale* | | X | |
| Unidentified grass | -- | X* | |
| Unidentified crucifer | -- | X* | |
| *Agropyron albicans* | X | | X |
| *Amelanchier alnifolia* | X | | X |
| *Aster laevis* | X | | X |
| *Astragalus drummondii* | X | | X |
| *Astragalus flexuosus* | X | | X |
| *Astragalus crassicarpus* | X | | X |
| *Calamovilfa longifolia* | X | | X* |
| *Glycyrrhiza lepidota* | X | | X |
| *Juniperus horizontalis* | X | | X |
| *Lygodesmia juncea* | X | | X |
| *Monarda fistulosa* | X | | X* |
| *Orthocarpus luteus* | X | | X |
| *Penstemon nitidus* | X | | X* |
| *Petalostemon candidum* | X | | X |
| *Phlox hoodii* | X | | X |
| *Psoralea esculenta* | X | | X* |
| *Rhus trilobata* | X | | X* |
| *Agropyron trachycaulum* | X | X* | X* |
| *Agropyron smithii* | X | X* | X* |
| *Antennaria parvifolia* | X | X* | X |
| *Artemisia campestris* | X | X | X* |
| *Artemisia frigida* | X | X* | X* |
| *Aster ericoides* | X | X* | X* |
| *Astragalus striatus* | X | X | X* |
| *Bouteloua gracilis* | X | X* | X* |
| *Carex filifolia* | X | X* | X* |
| *Cryptantha nubigena* | X | X | X |
| *Erigeron caespitosus* | X | X | X |
| *Gaura coccinea* | X | X* | X* |
| *Helianthus subrhomboideus* | X | X | X* |
| *Koeleria macrantha* | X | X* | X* |

**Table 2** Plant species observed on the establishing grasslands on the Oldman River Dam and in a nearby native grassland. The asterisk indicates plant species occurring in plots.

| Taxa | Native | Occurrence | |
|---|---|---|---|
| | | Dam Grassland | Native Grassland |
| *Liatris punctata* | X | X* | X* |
| *Linum lewisii* | X | X | X* |
| *Muhlenbergia cuspidata* | X | X | X* |
| *Rosa arkansana* | X | X* | X* |
| *Stipa comata* | X | X | X |
| *Stipa viridula* | X | X* | X* |
| *Symphoricarpos occidentalis* | X | X* | X* |
| *Vicia americana* | X | X* | X |
| *Tragopogon dubius* | | X* | X* |
| *Poa pratense* | | X | X |

*leptophyllum*, *Linum rigidum*, *Helianthus annuus*, and *Ratibida columnifera*), and those that are well adapted to the harsh dryness of the open, south-facing slope.

There was little evidence that seeds have played a major role in the establishment of native plants on the dam. Exceptions include *Helianthus annuus* and *Linum rigidum*, which are annuals, *Ratibida columnifera*, a short-lived, native pioneer species, and weedy introduced species (e.g. *Lepidium campestre*). Shrubs such as *Amelanchier alnifolia*, *Juniperus horizontalis* and *Rhus* trilobata are slower growing than grasses and forbs and do not propagate readily from cuttings. Therefore, they are expected to establish at a later stage on the dam. Faster growing shrubs, and those that readily propagate from root and rhizome pieces, such as *Rosa* species and *Symphoricarpos occidentalis* are already establishing on the dam.

## 4 CONCLUSION

Diversity on the dam and abutments, is increasing but does not yet compare favourably to that found on the nearby, relatively undisturbed grassland community. Many of the species differ between disturbed and undisturbed sites, but there is some overlap. Species found exclusively on the undisturbed site are, for the most part, later successional species whereas those found only on the dam are generally early seral species. Total vegetation cover is increasing and is approaching the levels seen on the undisturbed grassland. No rare plants were observed growing

on the dam face, adjacent abutments, or in the undisturbed plots. Although weed and exotic invasion is occurring, it is not a problem now but monitoring should continue because perennial weeds and forage species such as alfalfa, sweet clover, smooth brome, timothy, and Canada thistle are highly competitive and if unchecked will eventually reduce community diversity.

It is highly likely that the initial use of native topsoil, and the seeding of wheatgrass species have been instrumental in the observed success of the revegetation on the dam and the adjacent abutments. Although a control site where native topsoil was not used was not surveyed for comparison, the vegetation establishment on the dam is proceeding more quickly than was expected. The increase in diversity of native plants is due, in part, to the choice of wheatgrasses which are not highly competitive and persistent, rather than aggressive agronomic species such as smooth brome, timothy, and sweet clover.

Continued monitoring, on an occasional basis (every 2-3 years), will provide information regarding the development of a native grassland on which to base decisions regarding this type of revegetation in the future.

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**Appendix 1.** Index of scientific and common names of plant species.

| Species | Common Name |
|---|---|
| **Graminoids** | |
| *Agropyron albicans* Scribn. & Smith | wheatgrass |
| *Agropyron dasystachyum* (Hook.) Scribn. | northern wheatgrass |
| *Agropyron pectiniforme* R. & S. | crested wheatgrass |
| *Agropyron trachycaulum* (Link) Malte | slender wheatgrass |
| *Agropyron smithii* Rydb. | western wheatgrass |
| *Avena fatua* L. | wild oats |
| *Avena sativa* L. | cultivated oats |
| *Bouteloua gracilis* (HBK) Lag. | buffalo grass |
| *Bromus inermus* Leyss. | awnless brome |
| *Calamovilfa longifolia* (Hook.) Scribn. | sand grass |
| *Carex filifolia* Nutt. | sedge |
| *Dactylis glomerata* L. | orchard grass |
| Grass species (unknown) | grass species |
| *Koeleria macrantha* (Ledeb.) J.A. Schultz f. | June grass |
| *Muhlenbergia cuspidata* (Torr.) Rybd. | plains muhly |
| *Phleum pratense* L. | timothy |
| *Poa pratense* L. | Kentucky bluegrass |
| *Stipa comata* Trin. & Rupr. | needle and thread grass |
| *Stipa viridula* Trin. | green needle grass |
| **Forbs** | |
| *Achillea millefolium* L. | common yarrow |
| *Allium cernuum* Roth | nodding onion |
| *Antennaria parvifolia* Nutt. | pussy toes |
| *Artemisia absinthium* L. | wormwood |
| *Artemisia campestris* L. | field sage |
| *Artemisia frigida* Willd. | pasture sagewort |
| *Artemisia ludoviciana* Nutt. | prairie sagewort |

**Appendix 1.** Index of scientific and common names of plant species.

| Species | Common Name |
|---|---|
| *Aster ericoides* L. | tufted white prairie aster |
| *Aster laevis* L. | smooth aster |
| *Astragalus bisulcatus* (Hook.) A. Gray | two-grooved milk vetch |
| *Astragalus crassicarpus* Nutt. | buffalo bean |
| *Astragalus drummondii* Dougl. *ex* Hook | milk vetch |
| *Astragalus flexuosus* Dougl. *ex* G. don | milk vetch |
| *Astragalus missouriensis* Nutt. | timber milk vetch |
| *Astragalus gilviflorus* Sheldon | cushion milk vetch |
| *Astragalus striatus* Nutt. | ascending purple milk vetch |
| *Cirsium arvense* (L.) Scop. | Canada thistle |
| *Cirsium vulgare* (Savi) Ten. | bull thistle |
| *Cirsium undulatum* (Nutt.) Spreng. | wavy-leaved thistle |
| *Chenopodium leptophyllum* (Nutt. ex Moq.) S. Wats. | goosefoot |
| *Cryptantha nubigena* (Greene) Payson | Cryptantha |
| *Erigeron caespitosus* Nutt. | fleabane |
| *Gaillardia aristata* Pursh | gaillardia |
| *Glycyrrhiza lepidota* L. | wild licorice |
| *Gaura coccinea* Pursh | scarlet butterfly-weed |
| *Grindelia squarrosa* (Pursh) | gumweed |
| *Gutierrezia sarothrae* (Pursh) Britt. & Rusby | broomweed |
| *Helianthus annuus* L. | common annual sunflower |
| *Helianthus subrhomboideus* Rydb. | rhombic-leaved sunflower |
| *Heterotheca villosa* (Pursh) Shinners | golden aster |
| *Hymenoxys richardsonii* (Hook.) Cockerell | Colorado rubber-plant |
| *Lactuca serriola* L. | prickly lettuce |
| *Lepidium campestre* (L.) R.Br. | pepperwort |
| *Liatris punctata* Hook. | dotted blazing star |
| *Linum lewisii* Pursh | wild blue flax |
| *Linum rigidum* Pursh | yellow flax |

**Appendix 1.** Index of scientific and common names of plant species.

| Species | Common Name |
|---|---|
| *Lygodesmia juncea* (Pursh) D. Don | skeleton-weed |
| *Medicago sativa* L. | alfalfa |
| *Melilotus officinalis* (L.) Lam. | yellow sweet clover |
| *Monarda fistulosa* L. | wild bergamot |
| *Opuntia polyacantha* Haw. | prickly pear cactus |
| *Orobanche fasciculata* Nutt. | clustered broom-rape |
| *Orthocarpus luteus* Nutt. | owl-clover |
| *Oxytropis monticola* A. Gray | late yellow loco-weed |
| *Penstemon nitidus* Dougl. ex Benth. | smooth blue beard-tongue |
| *Petalostemon candidum* (Willd.) Michx. | white prairie clover |
| *Petalostemon purpureum* (Vent.) Rydb. | purple prairie clover |
| *Phlox hoodii* Richards | moss phlox |
| *Potentilla pensylvanica* L. | cinquefoil |
| *Psoralea esculenta* Pursh | Indian bread-root |
| *Ratibida columnifera* (Nutt.) Wooton & Standl. | prairie cone-flower |
| *Senecio canus* Hook. | prairie groundsel |
| *Sphaeralcea coccinea* (Pursh) Rydb. | scarlet mallow |
| *Taraxacum officinale* Weber | common dandelion |
| *Tragopogon dubius* Scop. | goat's-beard |
| *Vicia americana* Muhl. | wild vetch |
| **Shrubs** | |
| *Amelanchier alnifolia* Nutt. | Saskatoon |
| *Juniperus horizontalis* Moench | creeping juniper |
| *Symphoricarpos occidentalis* Hook. | buckbrush |
| *Rhus trilobata* Nutt. | skunk-bush |
| *Rosa arkansana* Porter | prairie rose |

**Appendix 2. Raw data**

| Species | East #1 | East #2 | East #3 | West #1 | West #2 | West #3 | 1 Tier #1 | 1 Tier #2 | 1 Tier #3 | 2 Tier #1 | 2 Tier #2 | 2 Tier #3 | 3 Tier #1 | 3 Tier #2 | 3 Tier #3 | 3 Tier #4 | 4 tier #1 | 4 Tier #2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agr das | 1 | | 5 | | <1 | 1 | | | 5 | 10 | 3 | 1 | 5 | 10 | 20 | 10 | 5 | 5 |
| Agr pec | | | | | | | | | | | | 1 | | | | | | |
| Agr smi | 1 | 10 | 1 | | 5 | 3 | 10 | 1 | 10 | 5 | 5 | 1 | 2 | 1 | 5 | 12 | 5 | 2 |
| Agr spp | | | | | | | | | | | | | | | | | | |
| Agr tra | 10 | 20 | 10 | 10 | 10 | 6 | 40 | 10 | 25 | 20 | 20 | 20 | 20 | 30 | 10 | 20 | 10 | 10 |
| Ant pav | | 3 | | | | | | | | | | | | | | | | |
| Art cam | | | | | | | | | | | | | | | | | | |
| Art fri | 3 | 5 | 5 | 5 | 5 | 20 | 15 | 15 | 5 | | 10 | 8 | | | <1 | 10 | 2 | |
| Ast eri | 1 | 7 | | | | | <1 | 5 | | <1 | | | <1 | 2 | | | 5 | |
| Ast mis | | | | | | | | | | | <1 | | | | | | | |
| Ast str | | | | | | | | | | | | | | | | | | |
| Ave sat | | | | | | | | | | | | | | | | | | |
| Bou gra | 1 | | | | | | | | | | | 2 | | | | | | |
| Cal lon | | | | | | | | | | | | | | | | | | |
| Car fil | <1 | | | | | | | <1 | | | | | | | | | | |
| Cir und | | | | | | 3 | | | | | | 10 | | | | | | |
| Cru spp | | | | | | | | | | | | | | | | 3 | | |
| Eri cae | | | | | | | | | | | | | | | | | | |
| Gau coc | | | < 1 | | <1 | | | | | | | | | | | | | |
| Gut sar | | | | | 5 | | | | | | | 10 | | | | | | |
| Hel sub | | | | | | | | | | | | | | | | | | |
| Hym ric | | | 1 | | 1 | | | | | | | | | | | | | |
| Koe mac | 1 | 5 | 3 | | | 3 | | | | | | | | 2 | | | | |
| Lep cam | | | | | | | | | <1 | | | | | | | | | <1 |
| Lia pun | | | | 5 | | | | | | | | | | | | | | |
| Lin lew | | | | | | | | | | | | | | | | | | |
| Lin rig | <1 | < 1 | < 1 | | | <1 | | | | | | | <1 | | | | | |
| Med sat | | 1 | < 1 | | | | | | | | | | | | | | | |
| Mel off | | < 1 | | | | | | | | | | | | | | | | 5 |
| Mon fis | | | | | | | | | | | | | | | | | | |
| Mul cus | | | | | | | | | | | | | | | | | | |
| Oxy mon | 2 | | 1 | | | | | | | | <1 | | | | | | | |
| Pen nit | | | | | | | | | | | | | | | | | | |
| Pet pur | | | | | <1 | | | | | | | | | | | | | |
| Pso esc | | | | | | | | | | | | | | | | | | |
| Rat col | | | | | 2 | | | | | | | | | | | | | |
| Rhu tri | | | | | | | | | | | | | | | | | | |
| Ros ark | | 5 | | | | | | | | | | 1 | | | | | | |
| Sti vir | | | | | | | | | | | 3 | 5 | <1 | | | | | |
| Sym occ | | 5 | | | | | | | | | | 1 | | | | | | |
| Tra dub | | | 1 | | | | | | | | | | | | | | | |
| Vic ame | | 1 | < 1 | | | <1 | | | | | | | <1 | | | | | |
| Weed spp | | | | | | | | | | | | | | | | | | |
| Absolute | 20 | 62 | 27 | 20 | 28 | 36 | 65 | 31 | 45 | 35 | 41 | 60 | 27 | 45 | 35 | 55 | 27 | 22 |
| Litter | 5 | 30 | 15 | 25 | 5 | 20 | 60 | 10 | 30 | 40 | 20 | 20 | 15 | 25 | 25 | 25 | 10 | 10 |
| Ground | 75 | 8 | 58 | 55 | 67 | 55 | 20 | 59 | 20 | 25 | 39 | 30 | 58 | 30 | 75 | 25 | 65 | 70 |

| Species | Native #1 | Native #2 | Native #3 | Native #4 | Native #5 |
|---|---|---|---|---|---|
| | | | | | |
| Agr das | | | | | |
| Agr pec | | | | | |
| Agr smi | 5 | 15 | 10 | 8 | 5 |
| Agr spp | | | | | |
| Agr tra | 2 | 8 | 5 | 2 | 5 |
| Ant pav | | | | | |
| Art cam | 1 | | | | |
| Art fri | | 10 | 5 | 10 | 10 |
| Ast eri | | | | | 3 |
| Ast mis | | | | | |
| Ast str | | | | 5 | |
| Ave sat | | | | | |
| Bou gra | | | | 20 | 3 |
| Cal lon | 6 | | 5 | 2 | |
| Car fil | 2 | 8 | | | 10 |
| Cir und | | | | | |
| Cru spp | | | | | |
| Eri cae | | | | | |
| Gau coc | <1 | | | 1 | |
| Gut sar | | | | | |
| Hel sub | | | 2 | | |
| Hym ric | | | | | |
| Koe mac | | | 5 | 10 | 8 |
| Lep cam | | | | | |
| Lia pun | 1 | 2 | 1 | 2 | 2 |
| Lin lew | <1 | | | | |
| Lin rig | | | | | |
| Med sat | | | | | |
| Mel off | | | | | |
| Mon fis | | | 1 | | |
| Mul cus | 2 | | 15 | | |
| Oxy mon | | | | | |
| Pen nit | <1 | | | | |
| Pet pur | | | | | |
| Pso esc. | | 1 | | | 3 |
| Rat col | | | | | |
| Rhu tri | | | 15 | | |
| Ros ark | <1 | | 5 | | |
| Sti vir | | | | | 20 |
| Sym occ | | 20 | 2 | | |
| Tra dub | 1 | | | 2 | |
| Vic ame | | | | | |
| Weed spp | | | | | |
| Absolute | 20 | 64 | 71 | 62 | 69 |
| Litter | 30 | 30 | 20 | 15 | 50 |
| Ground | 50 | 15 | 30 | 25 | 5 |

| Species | 1991 p1 | 1991p2 | 1991 p3 | 1991p4 | 1991p5 | 1991p6 | 1991p7 | 1991p8 | 1991p9 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| Agr das | | | | | | | | | |
| Agr pec | | | | | | | | | |
| Agr smi | 1 | | | | | | | | |
| Agr spp | 10 | 5 | 5 | 3 | 20 | | 3 | 5 | 4 |
| Agr tra | | | | | | | | | |
| Ant pav | | | | | | | | | |
| Art cam | | | | | | | | | |
| Art fri | | | | | | | | | <1 |
| Ast eri | 1 | | | | <1 | | | 1 | |
| Ast mis | | | | | | | | | |
| Ast str | | | | | | | | | |
| Ave sat | 30 | 25 | 30 | 40 | 15 | 15 | 8 | <1 | 1 |
| Bou gra | 2 | 5 | | | 1 | | | | |
| Cal lon | | | | | | | | | |
| Car fil | | | | | | | | | |
| Cir und | | | | | | | | | |
| Cru spp | | | | | | | | | |
| Eri cae | <1 | | | | | | | | |
| Gau coc | | | | | | | | | |
| Gut sar | | | | | | | | | |
| Hel sub | | | | | | | | | |
| Hym ric | | | | | | | | | |
| Koe mac | | | 1 | | | | | | |
| Lep cam | | | | | | | | | |
| Lia pun | | | | | | | | | |
| Lin lew | | | | | | | | <1 | |
| Lin rig | | | | | | | | | |
| Med sat | | | | | | | | | |
| Mel off | | | | | | | | | |
| Mon fis | | | | | | | | | |
| Mul cus | | | | | | | | | |
| Oxy mon | | | | | | | | | |
| Pen nit | | | | | | | | | |
| Pet pur | | | | | | | | | |
| Pso esc. | | | | | | | | | |
| Rat col | | | | | | | | | |
| Rhu tri | | | | | | | | | |
| Ros ark | | | | | | | | | |
| Sti vir | | | | | | | | | |
| Sym occ | | | | | | | | | |
| Tra dub | | | | | | | | | |
| Vic ame | <1 | | | <1 | | | | <1 | |
| Weed spp | | | | | | 5 | 1 | | <1 |
| Absolute | 44 | 35 | 36 | 43 | 36 | 20 | 12 | 6 | 5 |
| Litter | | | | | | | | | |
| Ground | | | | | | | | | |